Construction of Hierarchical Models for Fluid Dynamics in Earth and Planetary Sciences : DCMODEL project

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1 Introduction

In recent researches for fluid motions of planetary atmospheres and in the planetary interiors, numerical experiments and simulations by use of massive computational resources become a popular approach. Numerical simulation models used in such studies not only calculate pure fluid motion but also incorporate various kinds of elemental physical processes, such as radiation, subgrid turbulence, phase changes of constituents and so on. However, the simulation models have become so complicated that it is not easy for a researcher to understand the program as a whole. As a result, it has become increasingly difficult to check the validity of the simulation model by recognizing the effect of a certain elementary physical process, or to reducing the system in order to build up a conceptual model. This has been recognized as a "model-gap" problem[1]. In order to fill the gap between high-end complex simulation models and process studies or simplified conceptual models, it is necessary to prepare a software environment that enables to perform multiple simultaneous numerical experiments and to compare these results by use of an arbitrary set of models in a hierarchical fashion with various levels of complexity ranging from high-end complex simulation models to simplified conceptual models or process study models.

In these circumstances, we are now proceeding "dcmodel project", where a series of hierarchical numerical models with various complexity is developed and maintained. In the followings, we introduce the features and lineup of the models of dcmodel project.

2 Features of the models of "dcmodel"

In "dcmodel project", a series of the numerical models are developed taking care of the following points.

- A common "style" of program codes assuring readability of the software
- Open source codes of the models to the public
- Scalability of the models assuring execution on various scales of computational resources
- Stressing the importance of documentation and presenting a method for writing reference manuals

3 Components of dcmodel

3.1 Gtool5

Fortran90 library "gtool5"[2] provides data input/output interfaces and various utilities commonly used in the models of dcmodel project. We adopted a self-descriptive data format netCDF. The interfaces of gtool5 library can reduce the number of operation steps for the data IO in the program code of the models compared with the interfaces of the raw netCDF library. By use of gtool5 library, procedures for data IO and addition of metadata for post-processing can be easily implemented in the program codes in a consolidated form independent of the size and complexity of the models. By this feature, readability of the program codes are improved such that numerical experiments and output data analyses can be easily performed, and as a result, it becomes more efficient to compare of numerical results of the models with various complexities.

3.2 ISPACK/SPML

ISPACK and SPML are the libraries for spectral transformations for various kinds of spectral models. ISPACK is a Fortran77 library developed by Keiichi Ishioka in Kyoto University, and provides (possibly) the fastest FFT subroutines in the world. SPML(SPMODEL library)[3] is a Fortran90 wrapper library of ISPACK. Most prominent feature is a series of array-handling functions with systematic function naming rules. By use of the functions of SPML, program source codes can now be written with a form which is easily deduced from the mathematical expressions of the governing equations.

3.3 SPMODEL

"SPMODEL"[3] is a collection of various sample programs using "SPML". These sample programs provide the basekit for simple numerical experiments of geophysical fluid dynamics. For example, SPMODEL includes 1-dimensional KdV equation model, 2-dimensional barotropic, shallow water, Boussinesq models, 3-dimensional MHD dynamo models in rotating spherical

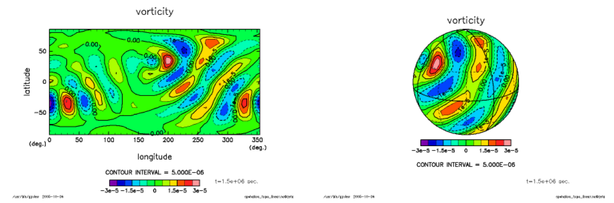

Fig. 1. An example of numerical result of a shallow water model on a rotating sphere.

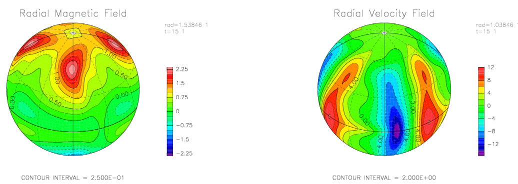

Fig. 2. An example of numerical benchmark of MHD dynamo in a rotating spherical shell. Left and right panels show the radial component of magnetic field at the outer boundary and radial velocity in the middle of the shell.

shells. These models are written in the common style in harmony with SPML functions. As a result, we can catch up the governing equations easily from the program codes.

3.4 Deepconv

"Deepconv"[4] is a non-hydrostatic model for the purpose of applications to the planetary atmospheres. The quasi-compressible system is adopted, and chemical reactions and phase changes of multiple atmospheric constituents are included in order to simulate the clouds in the Jovian and Martian atmospheres. 2-dimensional and 3-dimensional calculations are easily switched.

3.5 Dcpam

"Dcpam"[5] is a general circulation model (GCM) of the planetary atmospheres. It is based on the primitive equation system, and its dynamical part is calculated with a spectral method by use of ISPACK/SPML. Physical processes implemented are radiation, turbulent mixing, precipitation and simplified ground surface processes. The atmospheric circulations of the Earth, Mars, and (simplified) Venus can be calculated selectively with change of the namelist variables. Vertical 1-dimensional and axisymmetric 2-dimensional calculations are also possible.

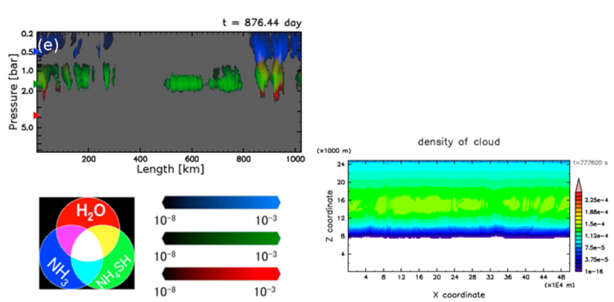

Fig. 3. Examples of the calculations of deepconv. Left and right panels show convection in a Jovian and Martian atmospheres, respectively.

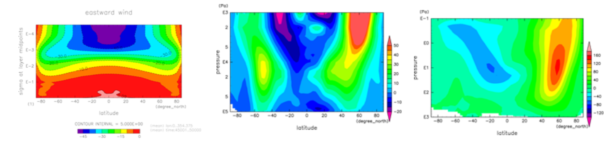

Fig. 4. Examples of numerical results with dcpam. From left to right, calculated zonal mean distributions of Venus, Earth and Mars.

3.6 Rdoc-f95

"Rdoc-f95" is a automatic generator of reference manuals of Fortran90/95 programs, which is an extension of ruby documentation tool kit "rdoc". It analyzes dependency of modules, functions, and subroutines in the multiple program source codes. At the same time, it can list up the namelist variables in the programs.

4 Conclusion

We have introduced the features and lineup of the models of dcmodel project, where a series of hierarchical numerical models with various complexity is developed and maintained. The series of hierarchical models enable us to conduct multiple numerical experiments with multiple models easily, which will lead to a deeper understanding of various phenomena in planetary atmospheres and interiors.

As is stated in "Introduction", one of the problems on the simulation models utilized in the research of the fields is that the source codes become so large that not only model users but also model maintainers cannot catch up what are realized by the model calculations. Expanded source code causes an "information explosion" for model developers and users. Development of hierarchical models represents one approach to overcoming such difficulties.

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